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THE STATISTICAL STRUCTURE OF OUTGOING RADIATION FIELDS

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ABSTRACT. The relationship between the statistical characteristics of outgoing radiation fields, measured by the "Cosmos-122" satellite, and cloud distribution is discussed. We introduce two-dimensional correlation functions of the radiation intensity in the 0.3 - 3.0 microns ranges, and of the radiation temperature in the 8 - 12 microns spectral interval, as well as the one-dimensional spectral density of the radiation temperature for individual directions. The aforenamed magnitudes were computed on the assumption that the outgoing radiation measurements are located at the nodes of some rectangular lattice of points.

It is demonstrated that two-dimensional correlation functions and the spectral density of outgoing radiation fields reflect in a certain manner the cloud distribution, and hence can be used as one of the quantitative representation methods of this distribution. 2 Tables, 4 Illustrations.

Along with television equipment, the "Cosmos-122" satellite also carried /51* actinometric instrumentation, scanning the earth's surface with an angular resolution of about 5 x 5°, in three intervals of the spectrum, i.e., 0.3 - 3.0, 8 - 12, and 3 - 30 microns. The measurements, performed in the 0.3 - 3.0 and 3.0 - 30.0 microns range reveal some data on the radiation balance of the earth atmosphere system. At the same time, measurements of short-wave radiation intensity yield additional information on the cloudiness. The brightness field in the 0.3 - 3.00 microns interval is closely related to the brightness field on the television picture. However, from the television image alone it is impossible to determine the absolute intensity values of the reflected radiation. This can be accomplished using the measurement data of the scanning radiometers.

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* Numbers in the margin indicate the pagination in the original foreign text.

Once the type, quantity and shape of clouds are established from high spatial resolution television images, it is possible to determine the relationship between the absolute values of the reflected radiation, and the cloud characteristics. Table 1 shows the recurrence periods of radiation intensity magnitudes in the 0.3 - 3.0 micron interval, for varying quantities of cloud, /52 computed from the data for several orbits of the "Cosmos-122" satellite. The data, tabulated in Table 1, indicate that the nature of the intensity distribution of reflected radiation does indeed depend on the quantity of clouds.

TABLE 1. THE RECURRENCE OF THE INTENSITY VALUES OF REFLECTED SOLAR RADIATION

B	Quantity of clouds (Strength)				
	Clear	1 - 3	4 - 6	7 - 9	10
0—0,05	82	129	81	238	40
0,06—0,10	23	60	134	461	43
0,11—0,15	3	26	33	261	79
0,16—0,20	2	17	72	261	225
0,21—0,25	0	8	32	73	87
0,26—0,30	0	6	17	26	49
0,31—0,35	0	4	2	0	14
0,36—0,40	0	0	2	0	19
0,41—0,45	0	3	3	0	13
Total number of cases	110	253	376	1320	569

Actinometric measurements facilitate the investigation of the relationship between the statistical structure of outgoing radiation fields, and the cloud cover characteristics in the framework of a specific synoptic situation.

In this study, we consider the possibility of using two-dimensional correlation functions of outgoing radiation fields in the aforenamed spectral intervals as a quantitative characteristic of the structure of a given specific cloud distribution.

To this end, we calculated two-dimensional autocorrelation functions of the radiation temperature in the 8 - 12 microns spectral interval, and radiation intensities in channels of 0.3 - 3.0 and 3.0 - 30.0 microns

$$b_{ff}(\rho, \varphi) = \overline{f_i(r, \varphi) f_k(r - \rho, \varphi)},$$

where f is the radiation temperature or the radiation intensity, r is the radius vector of a certain given measurement, and ϕ is the angle of this vector with respect to the coordinate axes.

It was assumed that the direction along the scanning row is the abscissa axis, and the direction along the orbit's trajectory (perpendicular to the scanning row) is the ordinate axis. The pitch of the reticule with respect to the axis was 120 km, i.e., double the distance between the middles of subsequent scanning rows. This was due to the fact that the instrumentation installed in the "Cosmos-122" satellite performs the scanning in intervals of wavelengths of 8 - 12 and 3 - 30 microns alternately, i.e., over each row. In this particular instance, we selected rows that were obtained synchronously to the scanning rows in the 8 - 12 microns spectral interval.

The distance between the points along the X-axis is not constant. It varies from 50 km in the nadir point (midpoint of the scanning row) to 70 km at a distance of 500 km from the nadir. For computation purposes, we selected points that were not more than 500 km away from the nadir. There were 15 such measurements per scanning row. The number of measurements along the Y-axis equals the number of scanning rows. Notably, the points at which the measurements were made, are not at the nodes of a rectangular lattice, but rather at the nodes of a network that consists of parallelograms. This takes place

because the scanning row is not strictly perpendicular to the projection of the orbit's trajectory, but deviates from the vertical on account of the satellites motion by an angle of about 8°.

Thus, we are considering the computations of autocorrelation functions of the subject measurements, performed at points located at the nodes of an approximately rectangular and approximately regular lattice; the deviations from rectangularity and from regularity are insignificant. The measured elementary area corresponds to the spatial resolution of the device and measures 50 x 50 km in the nadir. The deviation of the location of the center of this area from the node of a rectangular regular lattice does not exceed 20 km, even at a 500 km distance from the nadir.

When we recall that under such conditions the device integrates the radiation from an area of approximately 70 x 70 km, it becomes obvious that deviations of such order hardly have any substantial influence upon the magnitude of each individual measurement. In other words, if we select a lattice of 15 x n points (where n is the number of rows) located symmetrically with respect to the orbit's projection, then such a lattice can be considered both regular and rectangular, and the measurements can be construed as being for all practical purposes obtained from elementary areas of the same magnitude. /53

The number of rows (n) cannot be too large, inasmuch as we must attempt to approach the geographic uniformity of the analyzed area, as well uniform solar illumination conditions. On the other hand, the number of the rows cannot be small, since otherwise we will not be able to derive a reliable correlation function for large distances. In our calculations, $n \approx 30$, which conforms to a distance of about 3,500 km along the axis.

Correlation functions were constructed over a lattice of 15 x 20 points. Under such conditions, a minimum of 420 pairs was used in the calculations.

We used normalized correlation functions, i.e., the tables of auto-correlation coefficients. The correlation coefficients were computed not for the values proper of the function (temperature of radiation intensity), but rather for their deviations from some mean value for the given chart. Using the tables of the derived correlation coefficients, we plotted fields of iso-correlates which, in turn, were compared, with the appropriate cloud fields (nephanalyses or turbidity analyses).

Even a visual comparison of these fields indicates that the configuration of the isocorrelates is closely related to the cloud distribution. It is also obvious that when the underlying surface is homogeneous with respect to temperature and brightness (e.g., the ocean table), then the anisotropy of the field of the readiation temperature and brightness is caused by the anisotropy of the cloud field.

As an example, consider the combined analysis of the cloud fields, the radiation temperature, reflected radiation intensity, as well as the appropriate two-dimensional autocorrelation functions.

Figure 1 shows a typical nephanalysis with plotted isolines of the reflected radiation intensity and radiation temperatures. These data were obtained upon processing television photographs and actinometric measurements, made by the "Cosmos-122" satellite on 18 August 1966, at about 4 o'clock (Moscow time) over Northeastern China and the adjacent Pacific ocean area.

The photographed area has a well pronounced frontal zone, extended in the west-east direction in the central part of the area, shown on Figure 1. According to conventional meteorological observations, the main front passed here at 3:00 (Moscow time) from a point with coordinates 29° northern latitude and 118° western longitude, moving east-north-east to a point with coordinates 33° southern latitude and 133° eastern longitude. Judging from the nephanalysis and ground observation data, in the cloud field the front corresponded to a wide trail of stratocumulus. This trail was almost totally

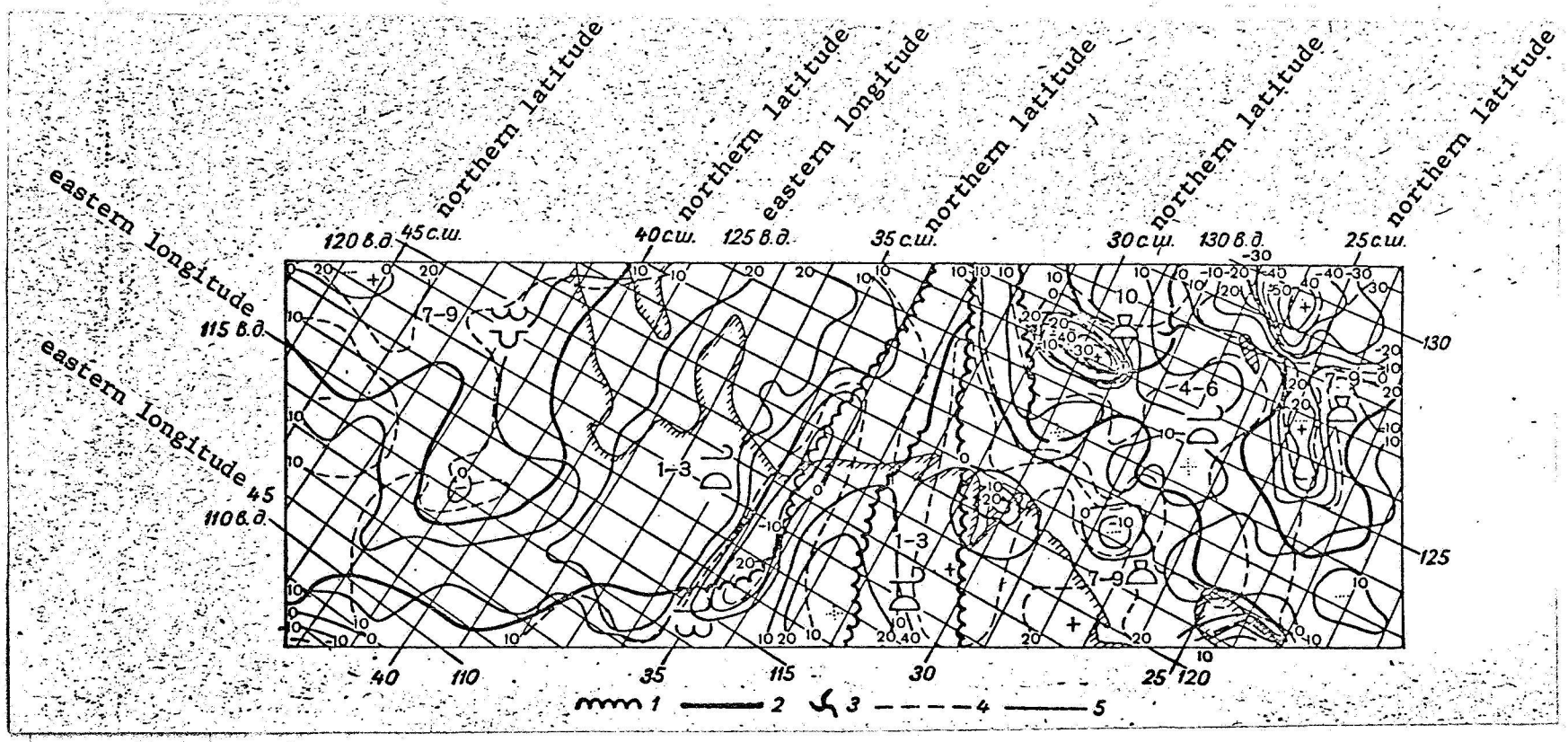

Figure 1. Nephanalysis (orturbidity analysis) reflected radiation fields, and radiation temperature fields from data of a television survey and actinometric measurements, performed by satellite "Cosmos-122", 18 August 1966, at about 4 o'clock (Moscow time) on the 796th orbit.

1. Strongly pronounced cloud field boundaries; 2.-Weakly pronounced cloud field boundaries; 3. cloud vortex center; 4. isoline of reflected radiation (cal/cm^2. min. ster); 5. radiation temperature isoline (in °C).

located in a warm air mass near the front. The northern boundary of this trail is very strongly pronounced and apparently coincides with the front line at the surface of the earth.

From the south, the boundary of the cloud trail is washed out. Individual accumulations of cumulonimbus are separated here by zones of slightly cloudy weather, where both cumuliform and cirriform clouds developed from anvils of cumulonimbus clouds. A particularly large accumulation of cumulonimbus clouds was discovered in an area with coordinates 29° northern latitude and 128° eastern longitude. According to synoptic data, this was the location of the tropical depression "Susan". This area is surrounded by a zone of slightly cloudy weather which shows thin trails of cirriform and cumulus clouds. Toward the center, these clouds form a coil-shaped vortex. Naturally, it is /55 impossible to determine an exact degree of congruence between the position of the center of the depression and the center of the cloud vortex, nor is it possible to make an analogous comparison of the position of the line of the aforenamed front and the trail of the frontal cloudiness.

For a variety of reasons (errors in the determination of the position of synoptic objects from weather charts, errors in the geographic reference of satellite data and discrepancies between observation times from meterological stations and from satellites) the difference between the positions of the depression center and the cloud vortex center amounts to 100 - 150 km.

Similar difficulties also arise in a combined analysis of television and actinometric data. The differences in the geometric properties of obtaining this type of satellite data (frame-for-frame television photography and row-for-row scanning by actinometric sensors), as well as small errors in the determination of the reciprocal position of the optical axes of this type of equipment result in discrepancies of up to 100 km between the geographic references of simultaneously obtained television and actinometric data. This is clearly demonstrated on Figure 1, where the isolines of the reflected

radiation intensity and radiation temperatures are obviously displaced toward the northwest in the left part of the photograph with respect to the boundaries of the cloud field on the nephanalysis.

If we take into account this shift, we will obtain a good agreement between outgoing radiation fields and the cloud field. Thus, we have a zone with increased brightness (over 0.10 cal/cm^2 min. ster.) and decrased radiation temperature (below +10°), conforming to the aforenamed trail of frontal cloudiness.

Expecially typical are individual areas, where the reflected radiation intensity exceeds 0.30 cal/cm^2 min. ster., and the radiation temperature is below 30°. In view of this, we may consider that these areas conform to accumulations of cumulonimbus clouds in the tropical depression zone "Susan". On the other hand, in clearing zones, the reflected radiation intensity is less than 0.10 cal/cm^2 min. ster., whereas the radiation temperature is over 10°.

Figure 1 clearly shows a well pronounced cloud trail of the upper and middle cloud level, merging from the north with a zone of frontal cumulonimbus clouds. This trail is caused by a jet stream. The stream axis passes from west-north-west toward east-south-east, so that the cloud trail is south of it. In outgoing radiation fields, this trail is very clearly pronounced, even through it is still displaced on the nephanalysis, with respect to the cloud boundaries. The reflected radiation intensity here ranges from 0.10 to 0.20 cal/cm^2 min. ster., whereby, as opposed to the cumulonimubus zone, the reflected radiation field is rather smooth. Accordingly, the radiation temperature values decrease smoothly from 10° at the edges of the cloud trail to -15° at its center.

The zone of slightly cloudy weather, located north of this trail, is typical on account of the low brightness (about 0.5 cal/cm^2 min. ster.) and high radiation temperatures (over 20°). The variability of the outgoing radiation is also quite low here, expecially where the zone of low cloud weather is located over the Yellow Sea.

Further north, judging from the nephanalysis and in complete agreement with ground observation data, is a zone of altocumulus and stratocumulus clouds. This cloudiness developed in cold air, in the forward part of the crest. The boundaries of the cloud accumulation are jagged, which is in complete agreement with the nature of the outgoing radiation fields, where the increase of /56
reflected radiation and the decrease of radiation temperature takes place more smoothly than it does in the previously considered instance. The maximum cloud brightness here reaches only 0.20 cal/cm^2 min. ster., whereas the minimal radiation temperature is 0°.

Consider now the respective autocorrelation functions of the outgoing radiation. Figures 2 and 3 show normalized two-dimensional correlation functions of the radiation temperature in the 8 - 12 micron spectral interval, and reflected radiation intensities in the 0.3 - 3 microns, spectral intervals. The correlation functions, refer to the area shown in Figure 1. The mean values of the radiation temperature $\bar{t}$ 18.0°C, the reflected radiation intensities $\bar{B}$ 0.11 cal/cm^2 min. ster., and the dispersions of these magnitudes D_t, D_B for the area shown on Figure 1 are 106.9°^{2} and 0.0039 (cal/cm^2 min. ster.)^2, respectively.

Notably, above all, is the clearly anisotropic nature of the outgoing radiation fields. We can assume that for distances that do not exceed approximatley 300 km the correlation coefficient is independent of the direction.

It is also apparent that the isocorrelates of the radiation temperature and of the reflected radiation intensity agree among themselves in a certain nature. Thus, a common feature of those fields is the elongation of the isocorrelates in a northerly direction with a transition through zero at a distance of about 1800 - 2000 km, as well as the presence of a negative correlation center in the northern corner of the map, conforming to distance of about 2500 - 2700 km (1).

(1) Let us recall that the expanse of the nephanalysis map on Figure 1 is about 3500 km in the direction along the orbit. The orbits trajecotry is directed from north-north-west toward the south-south-east.

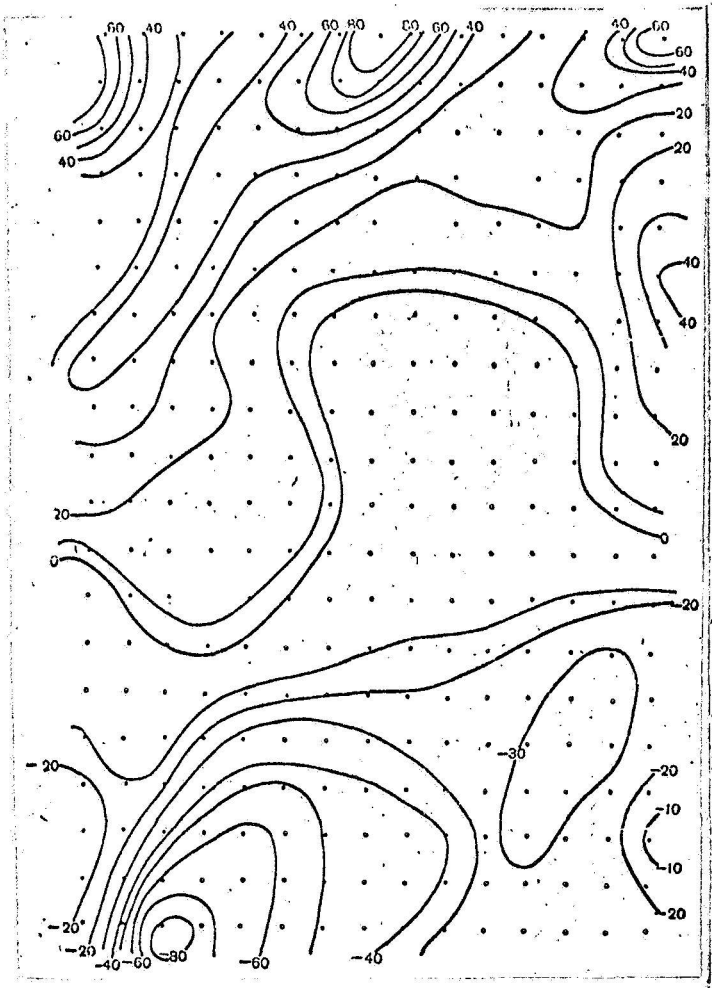

Figure 2. Normalized two-dimensional correlation function of the radiation temperature field in the 8 - 12 micron spectral interval.

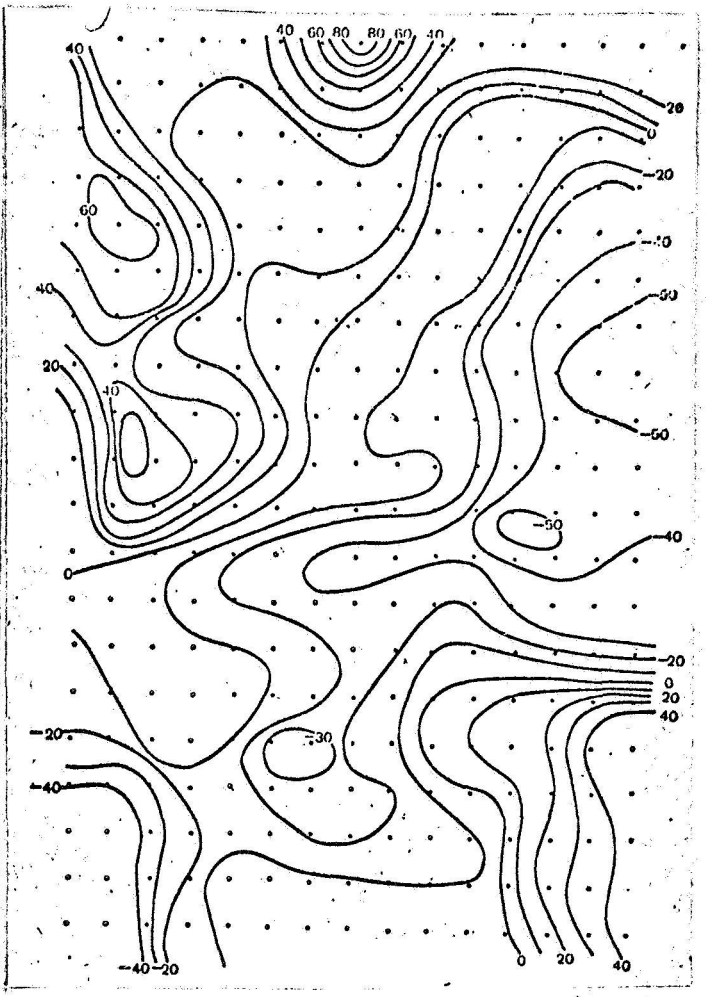

Figure 3. Normalized two-dimensional correlation function of the reflected radiation intensity field in a 0.3 - 3 micron spectral interval.

The correlation function decrease faster in a westerly and northwesterly-direction; transition through zero takes place at a distance of 500 to 800 km.

Such a configuration of the isocorrelate field is apparently caused by the fact that in the analyzed area the cloud formations are more uniform in /58 the west-easterly direction. However, correlation functions per se are not overly convenient for developing a clear concept of the relationship between the

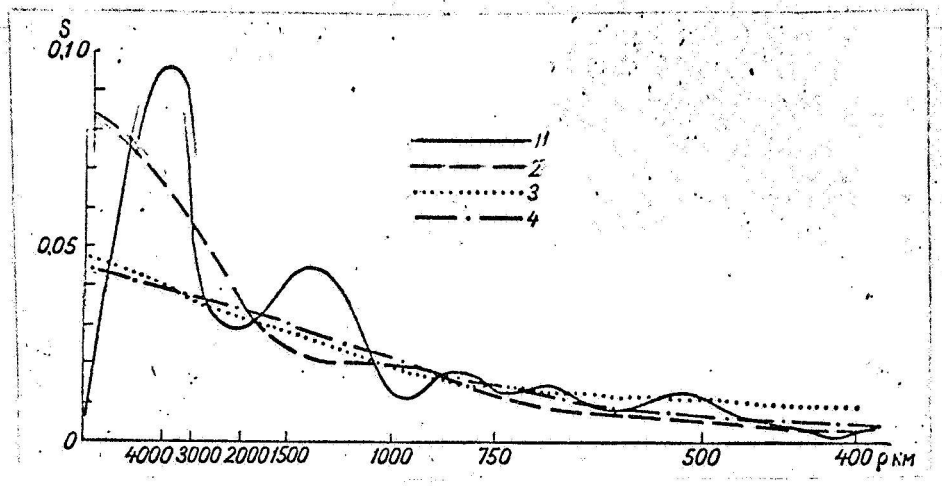

Figure 4. Spectra of the radiation temperature field for different directions:

1. along the orbit (from north-north-west to south-south-east); 2. from north to south; 3. from west to east; 4. across the orbit (from east-north-east to west-south-west).

specific distribution of the cloud cover and the statistical structure of the outgoing radiation field. The two-dimensional spectral density of the outgoing radiation field is a characteristic that is better for this purpose.

In this report, we will limit ourselves to a description of the behavior of spectral densities of radiation temperature fields, as they occur in the following directions: from north to south, from north-north-north-west to south-south-west (along the orbit), form east to west and from east-north-east to west-south-west (perpendicular to the orbit's trajectory).

The spectra of radiation temperature variations in the aforenamed directions are shown on Figure 4. Before we go into a description of their specific properties, it should be pointed out that the estimate of a two-dimensional correlation function of a radiation temperature field is so rough that it is difficult to approximate it by some analytically given function. As a consequence, the spectra shown on Figure 4 were obtained by a numerical method, using the estimate of the correlation function per se. The smoothing was performed during the calculation.

The operating properties of the actinometric instrumentation of the "Cosmos-122" satellite permit us to estimate with accuracy the spectral density of the variation of the radiation temperature field along the satellite's orbit. The spectral density curve (Curve 1) shows two significant maxima.

The first maximum is at a wavelength of about 4000 km and reflects the overall lowering of the radiation temperature from northwest toward the southeast along the satellite flight route. This drop reflects the presence of a high frontal zone extended from west to east.

The second maximum is at a wavelength of 1400 km and reflects details of the frontal zone structure, namely an alternation of trails of frontal cloudines and jet flow cloudiness with clearings before and behind the front. The other /59 maxima on the spectral desnity curve have no statistical significance.

Three other spectra shown on Figure 4 reflect the statistical structure of the variations of the field of radiation temperatures across the flight path of the satellite (Curve 4), as well as in the direction north-south and east-west (Curves 2 and 3). The spectral densities in the very long wave region could not be computed for these directions with sufficient accuracy on account of the relatively small width of actinometric measurements performed by the satellite. The spectral graphs have no secondary maxima. With a view to these graphs, we can only conclude that in the direction from west-to-east, the long waves have on the average a relatively smaller amplitude than in the direction from north-to-south.

This is in full agreement with the field nephanalysis data (Figure 1) and again supports the contention that the field structure of the radiation temperature reflects the principal characteristics of the macroweather. It should be also pointed out that all spectra (Figure 4) show a spectral density minimum in the mezoscale wave region.

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